

1 CIP REPLACEMENT APPLICATION 09/804,613 — 84 PAGES

2 Title

3 An Apparatus and Method And Techniques for Measuring and Correlating  
4 Characteristics of Fruit With Visible/Near Infra-Red Spectrum

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6 Continuation In Part Application

7 This is a Continuation In Part Application copending from the nonprovisional  
8 parent application 09/524,329 entitled AN APPARATUS AND METHOD FOR  
9 MEASURING AND CORRELATING CHARACTERISTICS OF FRUIT WITH  
10 VISIBLE/NEAR INFRA-RED SPECTRUM to Ozanich as filed March 13, 2000.  
11 The applicant requests prosecution pursuant to 37 C.F.R. 1.53(b) and 1.78 and 35  
12 U.S.C. 120. New matter herein is added, for examination convenience, commencing  
13 with page 56 which follows the last line of the Detailed Description of the original  
14 application and precedes the claims.

15

16 Field of the Invention

17 The present disclosure relates generally to the use of the combined visible and  
18 near infra red spectrum in an apparatus and method for measuring physical  
19 parameters, e.g., firmness, density and internal and external disorders, and chemical  
20 parameters, e.g., molecules containing O-H, N-H and C-H chemical bonds, in fruit  
21 and correlating the resulting measurements with fruit quality and maturity  
22 characteristics, including Brix, acidity, density, pH, firmness, color and internal and  
23 external defects to forecast consumer preferences including taste preferences and  
24 appearance, as well as harvest, storage and shipping variables. With the present  
25 apparatus and method, the interior of a sample, e.g., fruit including apples, is  
26 illuminated and the spectrum of absorbed and scattered light from the sample is  
27 detected and measured. Prediction, calibration and classification algorithms are  
28 determined for the category of sample permitting correlation between the spectrum of  
29 absorbed and scattered light and sample characteristics, e.g., fruit quality and

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1 maturity characteristics.

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### **Background of the Invention**

3 The embodiments disclosed herein has a focus on combined visible and near-  
4 infrared (NIR) spectroscopy and its modes of use, major issues in the application of  
5 NIR to the measurement of O-H, N-H and C-H containing molecules that are  
6 indicators of sample quality including fruit quality and in particular tree fruit quality.

7 **Near-Infrared Spectroscopy Background:** Near-infrared spectroscopy has  
8 been used since the 1970's for the compositional analysis of low moisture food  
9 products. However, only in the last 10-15 years has NIR been successfully applied to  
10 the analysis of high moisture products such as fruit. NIR is a form of vibrational  
11 spectroscopy that is particularly sensitive to the presence of molecules containing C-  
12 H (carbon-hydrogen), O-H (oxygen-hydrogen), and N-H (nitrogen-hydrogen) groups.  
13 Therefore, constituents such as sugars and starch (C-H), moisture, alcohols and acids  
14 (O-H), and protein (N-H) can be quantified in liquids, solids and slurries. In addition,  
15 the analysis of gases (e.g., water vapor, ammonia) is possible. NIR is not a trace  
16 analysis technique and it is generally used for measuring components that are present  
17 at concentrations greater than 0.1%.

18 **Short-Wavelength NIR vs. Long-Wavelength NIR:** NIR has traditionally  
19 been carried out in the 1100-2500 nm region of the electromagnetic spectrum.  
20 However, the wavelength region of ~700-1100 nm (short wavelength-NIR or SW-  
21 NIR) has been gaining increased attention. The SW-NIR region offers numerous  
22 advantages for on-line and *in-situ* bulk constituent analysis. This portion of the NIR  
23 is accessible to low-cost, high performance silicon detectors and fiber optics. In  
24 addition, high intensity laser diodes and low-cost light emitting diodes are becoming  
25 increasingly available at a variety of NIR wavelength outputs.

26 The relatively low extinction (light absorption) coefficients in the SW-NIR  
27 region yields linear absorbance with analyte concentration and permits long,  
28 convenient pathlengths to be used. The depth of penetration of SW-NIR is also much  
29 greater than that of the longer wavelength NIR, permitting a more adequate sampling

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1 of the "bulk" material. This is of particular importance when the sample to be  
2 analyzed is heterogeneous such as fruit.

3 **Diffuse Reflectance Sampling vs. Transmission Sampling:** Traditional  
4 NIR analysis has used diffuse reflectance sampling. This mode of sampling is  
5 convenient for samples that are highly light scattering or samples for which there is  
6 no physical ability to employ transmission spectroscopy. Diffusely reflected light is  
7 light that has entered a sample, undergone multiple scattering events, and emerged  
8 from the surface in random directions. A portion of light that enters the sample is  
9 also absorbed. The depth of penetration of the light is highly dependent on the  
10 sample characteristics and is often affected by the size of particles in the sample and  
11 the sample density. Furthermore, diffuse reflectance is biased to the surface of a  
12 sample and may not provide representative data for large heterogeneous samples such  
13 as apples.

14 While transmission sampling is typically used for the analysis of clear  
15 solutions, it also can be used for interrogating solid samples. A transmission  
16 measurement is usually performed with the detector directly opposite the light source  
17 (i.e., at 180 degrees) and with the sample in the center. Alternately the detector can  
18 be placed closer to the light source (at angles less than 180 degrees), which is often  
19 necessary to provide a more easily detected level of light. Because of the long sample  
20 pathlengths and highly light scattering nature of most tree fruit, transmission  
21 measurements can only be performed in the SW-NIR wavelength region, unless  
22 special procedures are employed to improve signal to noise.

23 **NIR Calibration:** NIR analysis is largely an empirical method; the spectral  
24 lines are difficult to assign, and the spectroscopy is frequently carried out on highly  
25 light scattering samples where adherence to Beer's Law is not expected.  
26 Accordingly, statistical calibration techniques are often used to determine if there is a  
27 relationship between analyte concentration (or sample property) and instrument  
28 response. To uncover this relationship requires a representative set of "training" or  
29 calibration samples. These samples must span the complete range of chemical and  
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1 physical properties of all future samples to be seen by the instrument.

2 Calibration begins by acquiring a spectrum of each of the samples.

3 Constituent values for all of the analytes of interest are then obtained using the best  
4 reference method available with regards to accuracy and precision. It is important to  
5 note that a quantitative spectral method developed using statistical correlation  
6 techniques can perform no better than the reference method.

7 After the data has been acquired, computer models employing statistical  
8 calibration techniques are developed that relate the NIR spectra to the measured  
9 constituent values or properties. These calibration models can be expanded and must  
10 be periodically updated and verified using conventional testing procedures.

11 Factors affecting calibration include fruit type and variety, seasonal and  
12 geographical differences, and whether the fruit is fresh or has been in cold or other  
13 storage. Calibration variables include the particular properties or analytes to be  
14 measured and the concentration or level of the properties. Intercorrelations (co-  
15 linearity) should be minimized in calibration samples so as not to lead to false  
16 interpretation of a models predictive ability. Co-linearity occurs when the  
17 concentrations of two components are correlated, e.g., an inverse correlation exists  
18 when one component is high, the other is always low or vice versa.

#### 19 Application of NIR to Tree Fruit and Existing On-Line NIR

20 **Instrumentation:** A growing body of research exists for NIR analysis of tree fruit.  
21 NIR has been used for the measurement of fruit juice, flesh, and whole fruit. In juice,  
22 the individual sugars (sucrose, fructose, glucose) and total acidity can be quantified  
23 with high correlation ( $>0.95$ ) and acceptable error. Individual sugars can not be  
24 readily measured in whole fruit. Brix is the most successfully measured NIR  
25 parameter in whole fruit and can generally be achieved with an error of  $\pm 0.5$ -1.0 Brix.  
26 More tentative recent research results indicate firmness and acidity measurement in  
27 whole fruit also may be possible.

28 Only in Japan has the large-scale deployment of on-line NIR for fruit sorting  
29 occurred. These instruments require manual placement/orientation of the fruit prior  
30

1 to measurement and early versions were limited to a measurement rate of three  
2 samples per second. The Japanese NIR instruments are also limited to a single lane  
3 of fruit and appear to be difficult to adapt to multi-lane sorting equipment used in the  
4 United States of America. While earlier Japanese NIR instruments employed  
5 reflectance sampling, more recent instruments use transmission sampling.

6 In Koashi et al., U.S. Pat. No. 4,883,953, there is described a method and  
7 apparatus for measuring sugar concentrations in liquids. Measurements are made at  
8 two different depths using weak and strong infrared radiation. The level of sugar at  
9 depths between these two depths can then be measured. The method and apparatus  
10 utilizes wavelength bands of 950-1,150 nm, 1,150-1,300 nm, and 1,300-1,450 nm.

11 U.S. Pat. No. 5,089,701, to Dull et al., uses near infrared (NIR) radiation in  
12 the wavelength range of 800-1,050 nm to demonstrate measurement of soluble solids  
13 in Honeydew melons. An eight-centimeter or greater distance between the light  
14 delivery location to the fruit and the light collection location was found to be  
15 necessary to accurately predict soluble solids because of the thick rind.

16 Iwamoto et al., U.S. Pat. No. 5,324,945, also use NIR radiation to predict  
17 sugar content of mandarin oranges. Iwamoto utilizes a transmission measurement  
18 arrangement whereby the light traverses through the entire sample of fruit and is  
19 detected at 180 degrees relative to the light input angle. Moderately thick-skinned  
20 fruit (mandarin oranges) were used to demonstrate the method, which relies on a fruit  
21 diameter correction by normalizing (dividing) the spectra at 844 nm, where,  
22 according to the disclosed data, correlation with the sugar content is lowest. NIR  
23 wavelengths in the range of 914-919 nm were found to have the highest correlation  
24 with sugar content. Second, third and fourth wavelengths that were added to the  
25 multiple regression analysis equation used to correlate the NIR spectra with sugar  
26 content were 769-770 nm, 745 nm, and 785-786 nm.

27 In U.S. Pat. No. 5,708,271, Ito et al. demonstrates a sugar content measuring  
28 apparatus that utilizes three different NIR wavelengths in the range from 860-960 nm.  
29 The angle between light delivery and collection was varied between 0 and 180  
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1 degrees and it was concluded that the low NIR radiation levels that must be detected  
2 when a photo-detector is placed at 180 degrees relative to the radiation source are not  
3 desirable because of the more complicated procedures and equipment that are  
4 required. A correlation of NIR absorbance with sugar content of muskmelons and  
5 watermelons was found when an intermediate angle, which gave greater NIR  
6 radiation intensity, was detected. No size correction was necessary with this  
7 approach.

8 U.S. Pat. No. 4,883,953 to Koashi et al. uses comparatively long wavelengths  
9 of NIR radiation (i.e., >950 nm), while in U.S. Pat. Nos. 5,089,701 to Dull, and  
10 5,708,271 to Ito, wavelengths of NIR radiation used are greater than 800 nm and 860  
11 nm, respectively. In U.S. Pat. No. 5,324,945 to Iwamoto, the wavelengths of NIR  
12 radiation with the highest correlation to sugar content of mandarins were 914 nm or  
13 919 nm, when the fruit were measured on the equatorial or stem portion, respectively.  
14 All of these methods use near-infrared wavelengths of light to correlate with sugar  
15 content of whole fruit. No other quality parameters are measured by these  
16 techniques.

17 The four disclosed patents are similar to the apparatus and method described  
18 here in that the present disclosure also measures sugar content. Two of the patents  
19 (Pat. No. 5,089,701 and 5,324,945) NIR wavelengths less than 850 nm) Pat. No.  
20 5,089,701 discloses the operation of the invention within the range of "from about  
21 800 nanometers to about 1050 nanometers." U.S. Pat. No. 5,324,945 lists 914 nm or  
22 919 nm as the primary analytical wavelength correlated with whole fruit sugar  
23 content; multiple linear regression was used to add successive wavelengths to the  
24 model as follows: 769-770 nm (2nd wavelength added), 745 nm (3rd wavelength  
25 added), and 785-786 nm (4th wavelength added). In Pat. No. 5,089,701, addition of  
26 the fourth wavelength to the model only reduced the standard error of prediction  
27 (SEP) by 0.1-0.2 Brix, which is approaching or less than the error limits of the  
28 refractometer used to determine the reference ("true") Brix values.

29 Other similarities between the method and apparatus described herein with the  
30

1 four patents listed above include the use of multivariate statistical analysis to  
2 establish correlation of the near-infrared spectral data with sugar content of whole  
3 fruit. Most also use data processing techniques such as second derivative  
4 transformation and some type of spectral normalization. All of these methods for  
5 relating NIR spectra to chemical or physical properties are well known to those  
6 practiced in the art of NIR spectroscopy.

7 The foregoing patents and printed publications are provided herewith in an  
8 Information Disclosure Statement in accordance with 37 CFR 1.97.

9 Summary of the Invention

10 Research groups around the world continue to explore the applications of near  
11 infrared spectroscopy to tree fruit. The apparatus and process disclosed herein is of  
12 the nondestructive determination or prediction of O-H, N-H and C-H containing  
13 molecules that are indicators of sample qualities, including fruit such as apples,  
14 cherries, oranges, grapes, potatoes, cereals, and other such samples, using near-  
15 infrared spectroscopy. Prior art has utilized spectrum from 745nm and above. This  
16 disclosure is of 1) the utilization of the spectrum from 250 nm to 1150 nm for  
17 measurement or prediction of one or more parameters, e.g., Brix, firmness, acidity,  
18 density, pH, color and external and internal defects and disorders including, for  
19 example, surface and subsurface bruises, scarring, sun scald, punctures, watercore,  
20 internal browning, in samples including fruit; 2) an apparatus and method of  
21 illuminating the interior of a sample and detecting emitted light from samples  
22 exposed to the above spectrum in at least one spectrum range and, in the preferred  
23 embodiment, in at least two spectrum ranges of 250 to 499nm and 500nm to 1150nm;  
24 3) the use of the chlorophyll absorption band, peaking at 680nm, in combination with  
25 the spectrum from 700nm and above to predict one or more of the above parameters;  
26 4) the use of the visible pigment region, including xanthophyll, from approximately  
27 250nm to 499nm and anthocyanin from approximately 500 to 550nm, in combination  
28 with the chlorophyll band and the spectrum from 700nm and above to predict the all  
29 of the above parameters.

30

1 Prior art has only examined spectrum from fruit for the prediction of Brix.  
2 This disclosure is of the examination of a greater spectrum using the combined  
3 visible and near infrared wavelength regions for the prediction of the above stated  
4 characteristics. The apparatus and method disclosed eliminates the problem of  
5 saturation of light spectrum detectors within particular spectrum regions while  
6 gaining data within other regions in the examination, in particular, of fruit. That is,  
7 spectrometers with CCD (charge coupled device) array or PDA (photodiode array)  
8 detectors will detect light within the 250 to 1150nm region, but when detecting  
9 spectrum out of fruit will saturate in regions, e.g., 700 to 925nm, or the signal to  
10 noise (S/N) ratio will be unsatisfactory and not useful for quantitation in other  
11 regions, e.g., 250 to 699nm and greater than 925nm, thus precluding the gaining of  
12 additional information regarding the parameters above stated. Thus disclosed herein  
13 is an apparatus and method permitting 1) the automated measurement of multiple  
14 spectra with a single pass or single measurement activity by detecting more than one  
15 spectrum range during a single pass or single measurement activity, 2) combining the  
16 more than one spectrum range detected, 3) comparing the combined spectrum with a  
17 stored calibration algorithm to 4) predicting the parameters above stated.

18 In each instance in the method and apparatus disclosed herein there will be a  
19 dual or plural spectrum acquisition from a sample from different spectrum regions.  
20 This is accomplished by 1) serially acquiring data from different spectrum regions  
21 using different light source intensities or different detector/spectrometer exposure  
22 times using a single spectrometer; 2) acquiring data in parallel with multiple  
23 spectrometers using different light intensities, e.g., by varying the voltage input to a  
24 lamp, or different exposure times to the spectrometers; however, different exposure  
25 times leads to sampling errors particularly where a sample is moving, e.g., in a  
26 processing line, due to viewing different regions on a sample; and 3) with multiple  
27 spectrometers using the same exposure time, constant lamp intensity with dual or a  
28 plurality of light detectors including neutral density filtered light detectors (where  
29 filtered light detectors giving the same effect as using a shorter exposure time). This  
30



1 approach provides dual or plural spectra with good signal to noise ratio for all  
2 wavelengths intensities using a single light source intensity and the same exposure  
3 time on all spectrometer detectors. This approach uses at least one filtered light  
4 detector using filtered input 82 to the spectrometer 170 rather than different exposure  
5 times. A filter can be any material that absorbs light with equal strength over the  
6 range of wavelengths used by the spectrometer including but not limited to neutral  
7 density filters, Spectralon, Teflon, opal coated glass, screen. The dual intensity  
8 approach using two different lamp voltages proves problematic because the high and  
9 low intensity spectra are not easily combined together due to slope differences in the  
10 spectra. The dual exposure approach yields excellent combined spectra, which are  
11 necessary for firmness and other characteristic prediction and also improves Brix  
12 prediction accuracy.

13 Measurements are disclosed, with the apparatus and process of this disclosure,  
14 which are made simultaneously in multiple sample types, e.g., where samples are  
15 apples, measurement is independent of a particular apple cultivar, using a single  
16 calibration equation with errors of  $\pm 1-2$  lb. and  $\pm 0.5-1.0$  Brix. This disclosure  
17 pertains to laboratory, portable and on-line NIR analyzers for the simultaneous  
18 measurement of multiple quality parameters of samples including fruit. Depending  
19 on the application or particular characteristic sought to be predicted or measured, a  
20 variety of calibration models may be used, from universal to highly specific, e.g., the  
21 calibration can be specific to a variety, different geographical location, stored v. fresh  
22 fruit and other calibrations.

23 Disclosed here is the greater role NIR technology will play as a tool for  
24 grading sample qualities including fruit quality. The unique ability of NIR statistical  
25 calibration techniques to extract non-chemical "properties" provides a technique for  
26 development of a general NIR "quality index" for tree fruit. This general "quality  
27 index" combines all of the information that could be extracted from the NIR spectra  
28 and includes information about Brix, acidity, firmness, density, pH, color and  
29 external and internal disorders and defects.

30

1       The near-infrared wavelength region below 745 nm has not been explored by  
2 prior investigations. Generally, the prior art design and or apparatus utilized was  
3 such that longer wavelength regions provided adequate data. The prior art for  
4 measuring sugar content in liquids and whole fruits using near-infrared spectroscopy  
5 utilizes longer wavelengths of radiation. No prior art exists for measuring other  
6 important quality parameters such as firmness, acidity, density and pH. No prior art  
7 has correlated consumer taste preferences with the combined NIR determination of  
8 multiple quality parameters such as sugar, acidity, pH, firmness, color, and internal  
9 and external defects and disorders.

10       It will be shown in this patent that the wavelength region from 250-1150 nm  
11 can be used to nondestructively measure not only sugar content (Brix) in various  
12 whole fruit, but firmness, density, acidity, pH, color and internal and external defects  
13 as well. For example, density of oranges is measured and is correlated to quality,  
14 e.g., freeze damaged fruit and dry fruit typically have lower density than good quality  
15 fruit and lower water content (i.e., greater dry matter content). NIR density  
16 measurement can be used to remove poor quality fruit in a sorting/packing line or at  
17 the supermarket. Information about color pigments and chlorophyll, related to  
18 maturity and quality, are obtained from 250 to approximately 699 nm. From  
19 approximately 700-1150 nm, the short wavelength NIR region, C-H, N-H, O-H  
20 information is obtained. Combining the visible and NIR region gives more analytical  
21 power to predict chemical, physical and consumer properties, particularly for fruit.  
22 All of these parameters can be determined simultaneously from a combined  
23 visible/NIR spectrum. Multiple parameters can be combined to arrive at a "Quality  
24 Index" that is a better measure of maturity or quality than a single parameter.

25       Absorption of light by whole fruit in the approximately 250-699 nm region is  
26 dominated by pigments, including chlorophyll (a green pigment) which absorbs in the  
27 approximately 600-699 nm region. Chlorophyll is composed of a number of  
28 chlorophyll-protein complexes. Changes in these chlorophyll-protein complexes and  
29 changes in other pigments, most notably anthocyanin (red pigment) and xanthophylls  
30

1 (yellow pigments), are related to the maturation and ripening process. Chlorophyll  
2 and pigments are important for determining firmness.

3 While the NIR wavelengths of 700-925 nm and longer have been readily  
4 accessible to common near-infrared spectrometers, shorter wavelengths have not  
5 typically been explored for the following reasons: 1) lead-salt and other detector  
6 types, e.g., InGaAs, were not sensitive to shorter wavelengths; 2) light diffraction  
7 gratings were blazed at longer wavelengths yielding poor efficiency at short  
8 wavelengths; 3) light sources did not have enough energy output at shorter  
9 wavelengths to overcome the strong light absorption and scattering of biological  
10 (plant and animal) material in the visible region (250-699 nm).

11 Disclosed herein is an apparatus and method for measurement, with the  
12 visible/near-infrared (VIS/NIR) spectroscopic technique for sugar content (also  
13 known as Brix or soluble solids, which is inversely related to dry matter content),  
14 firmness, acidity, density, pH, color and internal and external defects and disorders.  
15 The apparatus and method is successful in measuring one or more such characteristic  
16 in apples, grapes, oranges, potatoes and cherries. Demonstrated in this disclosure is  
17 the ability to combine chemical and physical property data permitting the prediction  
18 of consumer properties, such as taste, appearance and color; harvest variables, such as  
19 time for harvest; and storage variables such as prediction of firmness retention and  
20 time until spoilage.

#### 21 Brief Description of the Drawings

22 The foregoing and other features and advantages of the present disclosure will  
23 become more readily appreciated as the same become better understood by reference  
24 to the following detailed description of the preferred embodiment and additional  
25 embodiments of the disclosure when taken in conjunction with the accompanying  
26 drawings, wherein:

27  
28 FIG. 1 is a top plan showing an embodiment of the disclosure illustrating a sample  
29 holder having a securing or spring biasing article urging a holding article in contact  
30

1 with a sample having a sample surface, a light detector having a light detector  
2 securing or spring biasing article and light sources proximal the sample surface with  
3 the light sources positioned in relation to the light sensor generally orthogonal to the  
4 sample surface. An optional filter may be positioned between the light source and the  
5 sample or between the sample and a spectrometer(s). The light sources may be  
6 controlled by the CPU. The output from the light sensor becomes the input to a light  
7 detector such as a CCD array within a spectrometer.

8

9 Fig. 1A is a side elevation section of Fig 1.

10

11 Fig. 1B is a side elevation section of Fig 1 with no sample additionally showing a  
12 light source securing article.

13

14 Fig. 1C is a flow diagram demonstrating the method of this invention. The flow  
15 diagram is schematically representative of all embodiments of this disclosure.

16

17 Fig. 1D is a flow diagram demonstrating the method and apparatus illustrating the  
18 light source(s) which illuminate a sample, light collection channels 1...n (light  
19 detector 1...n) of the spectra from a sample delivered as input to a spectra measuring  
20 device, shown here as spectrometer 1...n. Spectrometer 1...n channels output 1...n are  
21 converted from analog to digital and become, for each channel, input to a CPU. The  
22 CPU is computer program controlled. The CPU output is also for each channel 1....n.

23

24 Fig. 1E is a flow diagram demonstrating the method and apparatus illustrating the  
25 light source(s) 120 as a broad band source which illuminates a sample 30; at least one  
26 discrete wavelength filtered (bandpass) photodetectors 255 having filters 130 for light  
27 collection channels 1...n from a sample 30. In this embodiment a light source 120  
28 with lamp 123 is controlled by a CPU 172. The spectrum detected from the sample

29

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1 surface 35 may be communicated by fiber optic fibers as light detectors 80 to the  
2 photodetectors 255.

3

4 Fig. 1F is a flow diagram demonstrating the method and apparatus illustrating the  
5 light source(s) provided by at least one discrete wavelength light emitting diodes 257  
6 to illuminate a sample 30; at least one broadband photodetector 255 and at least one  
7 broadband photodetector 255 for each LED 257 for light collection channels 1...n  
8 (photodetector 1...n) of the spectra from a sample.

9

10 Fig. 2 is a top plan depicting at least one light source, with a single light source  
11 shown in this illustration, with optional filter and with at least one light detector, with  
12 a plurality of light detectors illustrated, proximal to the sample surface. This  
13 depiction demonstrates an orientation of light detectors relative to the direction of  
14 light cast on the sample surface with one light detector oriented at approximately 45  
15 degrees to the direction of the light cast by the light source and a second light detector  
16 oriented at approximately 180 degrees from the direction of the light cast by the light  
17 source.

18

19 Fig. 2A is a section elevation view of Fig 2 with the sample removed.

20

21 Fig. 2B is a top plan depicting a single light source, with optional filter(s) and with  
22 multiple light detectors proximal and directed to illuminate the sample surface with  
23 both light detectors oriented at approximately 45 degrees to the direction of the light  
24 cast by the light source.

25

26 Fig. 2C is an elevation view of Fig 2B.

27

28 Fig. 2D is a section from Fig. 2C depicting a shielding method or apparatus, e.g., in  
29 the form of a bellows or other shielding article shielding the light detector from

30

1 ambient light and directing the light detector to detect light spectrum output from the  
2 sample.

3

4 Fig. 2E is a detail of a shielding device between the light detector of Fig. 2 and a  
5 sample. Shown in this illustration is a shield in the form of a bellows. Other  
6 shielding apparatus and methods will provide like shielding structure.

7

8 Fig. 3 is a top plan depicting an alternative embodiment of a light source and light  
9 detector configuration where the light source is communicated by fiber optics.

10

11 Fig. 3A is a section from Fig. 3. The light source and light detector may be as  
12 described for Fig. 1. Alternative light source may be provided by a plurality of light  
13 sources, which may be sequentially fired light emitting diodes emitting discrete  
14 wavelengths; where LEDs are employed, the light sensor or light detector may be a  
15 broadband photodiode detector central to concentrically positioned LEDs. Fig. 3A  
16 illustrates light sources or lamps (and alternatively LEDs) concentrically positioned  
17 around a broadband light detector (and alternatively a broadband photodiode detector  
18 255, such light sources as well as the light sources 120/LEDs 257, can be placed in  
19 other arrangements. These and other configurations also apply in the use of filtered  
20 photodetectors 255 and broadband lamp 123 design.

21

22 Fig. 3B is a section from Fig. 3 showing an embodiment where light detectors or light  
23 detection fibers surround a least one light source or light source fibers. The light  
24 source and light detector may be as described for Fig. 1. In this representation, the  
25 centrally positioned light source may be a lamp or light transmitted from a  
26 spectrometer; the light detection may be by fiber optics transmission with discrete  
27 bandwidth filters between the fiber optics fiber and the sample limiting the  
28 transmission by any single or group of fibers.

29

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1 Fig. 4 is a top plan depicting an alternative embodiment of a light source and light  
2 detector configuration.  
3  
4 Fig. 5 is a top plan depicting an alternative embodiment of the disclosure in a hand  
5 held case showing a light source and light detector configured in a sampling head. In  
6 this embodiment at the sampling head at least one light source, which may be a  
7 tungsten halogen lamp, is positioned in relation to discrete-wavelength filtered  
8 photodetectors. A shield is illustrated as an ambient shield. The operation of this  
9 embodiment is seen in Fig. 1E wherein all components are encased within the case  
10 250.  
11  
12 Fig. 5A is a side elevation of Fig 5 depicting a sample positioned on the sampling  
13 head.  
14  
15 Fig. 5B is an illustration of the embodiment of Fig. 5 where the sampling head 260 is  
16 in the form of a clamp 263. The light detector 80 is depicted as a fiber optic fiber  
17 transmitting spectrum from the sample to an array of filtered 130 photodetectors 255  
18 or a spectrometer 170. The output 82 will be managed as shown in Fig. 1D or 1E.  
19  
20 Fig. 5C is a section from Fig. 5B of the array of filtered 130 photodetectors 255. A  
21 positioning structure 79 secures and positions the light detector 80 relative to the  
22 filtered 130 photodetectors 255.  
23  
24 Fig. 5D is an illustration of the embodiment of Fig. 5 where in at least one clamp jaw  
25 266 structure at least one arc photodetector array 90.  
26  
27 Fig. 5E is a section of the photodetector 255 array of Fig. 5D.  
28  
29  
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1 Fig. 6 is a top plan depicting an additional embodiment of the disclosure in a hand  
2 held case. The operation of this embodiment is seen in Fig. 1F wherein all  
3 components are encased within the case 250.

4

5 Fig. 6A is a section elevation of Fig 6 depicting the sampling head showing the  
6 ambient shield, light emitting diodes and photodetector or light detector fixed by  
7 affixing articles within the sampling head. The output from the light detector is  
8 depicted as well as is the case.

9

10 Fig. 6B is an elevation representative of an additional embodiment of the disclosure  
11 of this invention and of the embodiment of Fig. 6.

12

13

14 Fig. 6C is a plan view of the embodiment of Fig. 6B illustrating a plurality of light  
15 detectors, illustrated here as fiber optic light detectors. Shown in this illustration are  
16 two light detectors with one proximal the light source and another distal from the  
17 light source.

18

19 Fig. 6D is a section detail view from Fig. 6B illustrating the light source, lamp, light  
20 source securing article, case, sampling head, light detectors positioned proximal and  
21 distal from the light source, light source input and light detector outputs.

22

23 Fig. 6E is an elevation view of an embodiment of the disclosure of Fig. 6 wherein the  
24 sampling head structure provided the ambient shield structure.

25

26 Fig. 6F is a section detail from Fig. 6E showing light detectors affixed within the  
27 sampling head ambient shield positioned proximal and distal from the light source, a  
28 lamp with lamp input, light detector outputs and a case.

29

30



1 Fig. 7 is a side elevation showing another embodiment in a packing/sorting line form  
2 of the disclosure. The light source and light detector are positioned proximal the  
3 sample.

4  
5 Fig. 7A is a section elevation of Fig 7 depicting the light source, and sample  
6 conveyance system, bracket fixture, light source securing article, lamp input and  
7 spectrometer as a sample moves into illumination from the light source and toward  
8 the light detector.

9  
10 Fig. 7B is a section elevation of Fig 7 depicting the light detector, and sample  
11 conveyance system, bracket fixture, light detector fixture, light detector output,  
12 spectrometer, and detector as a sample moves toward and under the light detector.

13  
14 Fig. 7C is an elevation depicting at least one light detector 80 and as shown a  
15 plurality of light detectors 80 representative of measurements of a plurality of  
16 spectrum regions.

17  
18 Fig. 7D is a section from Fig. 7C showing the lamp 123 oriented to illuminate the  
19 sample from the side. As illustrated, the sample as an apple is illuminated from the  
20 stem side.

21  
22 Fig. 7E is a section from Fig. 7C showing one of the light detectors 80.

23  
24 Fig. 8 is a side elevation showing an additional embodiment of the apparatus  
25 disclosed in Fig. 7.

26  
27 Fig. 8A is a section elevation of Fig 8 depicting the light shield and at least one  
28 curtain, light source, and sample conveyance system as a sample moves into contact  
29 with and under the light shield. Fig. 8B is a section elevation of Fig 8 depicting the

30

1 light shield, at least one curtain, light detector and sample conveyance system as a  
2 sample moves into contact with and under the light shield.  
3  
4 Fig 9 is an elevation depicting an additional embodiment of the invention  
5 demonstrating at least one light detector 80 having an output 82 to a spectrometer 170  
6 having a detector 200.  
7  
8 Fig. 10 illustrates using spectroscopic sensors for measuring fruits and vegetables while in  
9 motion on a sample conveyor 295. Shown is a sample 30 with proximity sensing means  
10 340. Demonstrated is the sample conveyor 295, a case 250, collimating lens 78.  
11  
12 Fig. 10A is a section from Fig. 10 illustrating the proximity sensing means 340 in the form  
13 of reflectance means.  
14  
15 Fig. 11 illustrates the manner of taking a reference measurement of the light source 120  
16 lamp(s) 123 where intensity vs. wavelength output can also be obtained using reflecting  
17 means 360.  
18  
19 Fig. 12 and 13 illustrate the mechanical insertion of reference means 430 in or near the  
20 location where actual sample 30 is normally measured. Insertion is by insertion means  
21 including but not limited to an actuator system 400.  
22  
23 Fig. 14 and 14A illustrate a means of reducing the width of apparatus structure by mounting  
24 light source 120 lamps 123 distal from a sample 30 with spectrum from the sample 30  
25 directed by reflecting means 360 and lens 78 or reference light transmission means 320  
26 with spectra received via apertures 310.  
27  
28 Fig. 15 and 15A illustrates spectra detection from sample 30 other than discrete increments,  
29 such as apples, including, for example potato chips, where light source 120 lamps 123  
30

1 illuminate the sample(s) 30 with detectors 80 receiving input with light detector output 82  
2 conveyed as input to spectrometers 170 detectors 200. In this illustration a lens 130 is  
3 depicted between the sample 30 and the detector 80. Illustrations 15 and 15A depict in  
4 detail, with filter 130 and mounting means, a single detector 80.  
5 A CPU 172, controlled by computer program, is not depicted in Fig. 10, 10A, 11, 12, 13, 14,  
6 14A, 15 or 15A as a person of ordinary skill will appreciate such structure from viewing  
7 other drawings presented herein.

#### 8 Detailed Description

9 The apparatus and method disclosed herein is illustrated in Fig. 1 through 8.  
10 Fig. 1C, 1D, 1E and 1F are flow diagrams demonstrating the method of this  
11 invention. The flow diagram Fig. 1C is representative of all embodiments of this  
12 disclosure. The flow diagram Fig. 1D illustrates one or more light sources 120 and  
13 multiple channels from light detector 50 through final prediction of sample  
14 characteristic. Fig. 1D demonstrates the method and apparatus of this disclosure  
15 illustrating the light source(s) 120, which may be lamps 123 or other light sources,  
16 which illuminate a sample 30 interior 36, light collection channels 1...n, composed  
17 for example of fiber optic fibers 80 or photodetectors 255, e.g., light detector 1...n, of  
18 the spectra from a sample 30 delivered as input 82 to a spectra measuring device,  
19 shown here as spectrometer(s) 1...n. 170. In the preferred embodiment a light source  
20 120 with lamp 123 is external to the spectrometer and is controlled by a CPU 172  
21 which triggers power 125 to the light source 120 lamp 123. Spectrometer 1...n 170  
22 channels output 1...n are converted from analog to digital by A/D converters 1...n  
23 171 and become, for each channel, input to a CPU 172. The CPU 172 is computer  
24 program controlled with each step, following the CPU 172 in this flow diagram is  
25 representative of a computer program controlled activity. A CPU 172 output is  
26 provided for each channel 1...n where the steps of 1) calculation of absorbance  
27 spectra 173 occurs for each channel 1...n, 2) combine absorbance spectra 174 into a  
28 single spectrum encompassing the entire wavelength range detected from the sample  
29 by spectrometers 1...n 170, 3) mathematical preprocessing or preprocess 175, e.g.,  
30

1 smoothing or box car smooth or calculate derivatives, precedes 4) the prediction or  
2 predict 176, for each channel, comparing the preprocessed combined spectra 175 with  
3 the stored calibration spectrum or calibration algorithm(s) 177 for each characteristic  
4 1...x 178, e.g., Brix, firmness, acidity, density, pH, color and external and internal  
5 defects and disorders, for which the sample is examined, followed by 5) decisions or  
6 further combinations and comparisons of the results of quantification of each  
7 characteristic, 1...x, e.g., determination of internal and or external defects of disorders  
8 179, 180; determination of color 181; determination of indexes such as eating quality  
9 index 182, appearance quality index 183 and concluding with sorting or other  
10 decisions 184. Sorting or other decisions 184 may for example be input process  
11 controllers to control packing/sorting lines or may determine the time to harvest, time  
12 to remove from cold storage, and time to ship. The apparatuses depicted in Fig. 1  
13 through 8 do not all illustrate the entire flow diagram sequence from illumination of  
14 sample 30 through determination of the predicted result as is depicted in Fig. 1C, 1D,  
15 1E and 1F. For signal processing illustrations, reference is made to the indicated  
16 drawings.

17 Absorbance is calculated as follows: once the dark spectrum, reference  
18 spectrum and sample spectrum are collected, they are processed to compute the  
19 absorbance spectrum, which Beer's law indicates is proportional to concentration.  
20 The dark spectrum, which may include background/ambient light, is subtracted from  
21 both the sample spectrum and the reference spectrum. The log base 10 of the  
22 reference spectrum divided by the sample spectrum is then calculated. This is the  
23 absorbance spectrum. It is noted that dark and reference can be collected  
24 periodically, i.e., they do not necessarily need to be collected along with every sample  
25 spectrum. A stored dark and reference can be used if light source and detector are  
26 stable and don't drift. Pre-processing uses techniques known to those practiced in  
27 the art such as binning, smoothing, wavelength ratioing, taking derivatives, spectral  
28 normalizing, wavelength subtracting, etc. Then the processed absorbance spectrum  
29 will be compared with a stored calibration algorithm to produce an output  
30

1 representative or predictive of one or more characteristics, e.g., firmness, Brix, pH,  
2 acidity, density, color, and internal and external defects or acidity, of the sample 30.

3 Fig. 1E is a flow diagram demonstrating the method and apparatus illustrating  
4 the light source(s) 120 as a broad band source, such as a tungsten halogen lamp,  
5 which illuminates a sample 30; at least one, but in an embodiment a plurality, of  
6 discrete wavelength filtered (bandpass) photodetectors 255 having filters 130 provide  
7 spectrum detection for light collection channels 1...n (photodetector 1...n) of the  
8 spectra from a sample 30. In this embodiment a light source 120 with lamp 123 is  
9 controlled by a CPU 172 which triggers power 125 to the light source 120 lamp 123.  
10 The spectrum detected from the sample surface 35 may be communicated by fiber  
11 optic fibers as light detectors 80 to the photodetectors 255. The management of the  
12 detected spectra is as described for Fig. 1D. An alternative to this embodiment may  
13 use an AOTF, (acousto-optic tunable filter) to replace the at least one or a plurality of  
14 photodetectors 255 as the spectrum detection device.

15 Fig. 1F is a flow diagram demonstrating the method and apparatus illustrating  
16 the light source(s) provided by at least one, but in an embodiment a plurality of  
17 discrete wavelength light emitting diodes 257, which may be sequentially fired or  
18 lighted by a CPU trigger for power 125 to illuminate a sample 30; at least one  
19 broadband photodetector 255 and, in an alternative embodiment a least one  
20 broadband photodetector 255 for each LED 257, provide spectrum detection for light  
21 collection channels 1...n (photodetector 1...n) of the spectra from a sample. The  
22 management of the detected spectra is as described for Fig. 1D. Alternative light  
23 sources for this embodiment include but are not limited to tunable diode lasers, laser  
24 diode and a filter wheel placed between the light source(s) and sample or between the  
25 sample and photodetector(s).

26 Fig. 1, 1A and 1B depict an embodiment of a Nondestructive Fruit Maturity  
27 and Quality Tester 1 for measuring and correlating characteristics of fruit with  
28 combined Visible and Near Infra-Red Spectrum showing an embodiment of the  
29 disclosure illustrating a sample holder 5 having a securing or spring biasing article 9  
30

1 urging a holding article 12 against and in contact with a sample 30. The holding  
2 article depicted in Fig. 1 is illustrated as essentially a hemisphere sized to receive a  
3 sample 30. The sample has a sample surface 35. At least one light source 120 will  
4 be employed proximal the sample surface 35. The light source 120 is comprised of at  
5 least one lamp 123, optional filters 130. Here illustrated are two light sources 120  
6 each directed essentially orthogonally to the sample surface 35 and illuminating the  
7 sample 30 approximately 60 TO 90 degrees relative to each other. A light detector  
8 80 is depicted as directed to detect light from the sample surface 35 at approximately  
9 30 TO 45 degrees relative to the direction of the light cast from either light source  
10 120. The light detector 80 is illustrated as positioned by a light detector fixture 50  
11 having a light detector securing or spring biasing article 60 placing, holding and or  
12 urging a light detector 80 into contact with the sample surface 35. Monitoring of the  
13 light source 120 is depicted by light detectors 80 depicted as directed toward the lamp  
14 123 output; the output 82 of these reference light detectors 80 is detected by a  
15 reference spectrometer 170; an alternative to the use of two spectrometers 170 will be  
16 the sequential measurement of reference light detectors 80 and the light detector 80  
17 directed to the sample surface 35. All light detector 80 are fixed by light detector  
18 fixtures 50 by light detector securing or spring biasing articles 60 to a plate 7 or other  
19 containing device such as a case. The securing article 9 urging the holding article 12  
20 against the sample 30 also urges the sample against the light detector 80. The  
21 securing article 9 and holding article 12 in combination with the light detector 80 and  
22 light detector securing article 60 secure and prevent the sample 30 from movement.  
23 The sample 30 is shown, in Fig. 1, as an apple. The light sources 120 may be, for  
24 example, tungsten/halogen lamps. An optional filter 130 or filters 130 functioning as  
25 heat block, bandpass and or cutoff filters, separately or in combination, may be  
26 positioned between the lamp 123 and the sample 30 or between the sample 30 and the  
27 light detector 80. The light sources 120 may be lamps 123, provided for example by  
28 external 50Watt, 75 Watt, or 150 Watt lamp sources controlled by a CPU 172.  
29 Power 125 can be provided by power supply from a spectrometer 170 or from an  
30

1 alternate power supply. Both the light source(s) and the spectrometer(s) are  
2 controlled by a CPU 172 and their operation can be precisely controlled and  
3 optimally synchronized using digital input/output (I/O) trigger. The light detector 80,  
4 shown here as a fiber-optic sensor, provides a light detector output 82 which  
5 becomes the input to a spectrometer 170, or other spectrum measuring or processing  
6 instrument, which is detected by a detector 200, e.g., at least one light detection  
7 device or article, such as a CCD array which may be a CCD array within a  
8 spectrometer 170. The sample holder 5, light detector fixture 50 and light detector  
9 securing article 60 and light sources 120 with light source securing article 122 are  
10 affixed to a plate 7, for experimental purposes but will be otherwise enclosed and or  
11 affixed in a container, case, cabinet or other or other fixture for commercial purposes,  
12 e.g., applications include and are not limited to sample measurements on high speed  
13 sorting and packing lines, harvesters, trucks, conveyor-belts and experimental and  
14 laboratory. Other brackets, fixtures or articles may be employed to secure or position  
15 either sample holders 5, light detectors 50 and or samples 30 requiring only that the  
16 device or method used retain the sample 30 in position relative to the light source 120  
17 and light detector 50 during the period of measurement; fixing methods including  
18 welds, bolts, screws, glue, sheet metal forming and other methods may be used to  
19 secure such items for either experimental or commercial purposes..

20 Fig. 2, 2A, 2B, 2C, 2D and 2E depicts an alternative embodiment of the  
21 Nondestructive Fruit Maturity and Quality Tester 1 depicting a single light source  
22 120, with lamp 123 and optional filter 130 and with multiple light detectors 80 in  
23 contact with the sample surface 35. This depiction of the relative positioning of the  
24 light detectors 80 with the sample 30 or sample surface 35 is directed to the shielding  
25 of the light detector 80 from ambient light and is intended to demonstrate either direct  
26 contact between the light detector 80 and the sample surface 35 or shielded a shield  
27 84 composed, for example, by bellows, a foam structure or other pliable or  
28 compressible article or apparatus providing a sealing structure or shield method of  
29 insuring that the light detector 80 is shielded from ambient light and light from the  
30

1 light source 120 and receives light spectrum input solely from the sample 30. The  
2 positioning of the light source 120 relative to the light detectors 80 illustrate a  
3 positioning of one light detector 80 at angle theta of approximately 45 degrees to the  
4 direction of the light as directed by the light source 120 to illuminate the sample 30.  
5 The second light detector 80, in this illustration, is at angle gamma of approximately  
6 180 degrees to the direction of the light as directed by the light source 120. The  
7 positioning of the light detector 80 at approximately 180 degrees to the direction of  
8 the light as directed by the light source 120 may be a position utilized for the  
9 detection of internal disorders within the sample, e.g., internal disorders within  
10 Tasmania Jonagold apples, such as water core, core rot, internal  
11 browning/breakdown, carbon dioxide damage, and, in some cases, insect  
12 damage/infestation. The light detectors 80 in this illustration are suggestive of the  
13 many light detector 80 positions possible with the positioning dependent on the  
14 sample and the characteristic or characteristics to be measured or predicted. In this  
15 illustration the light detectors 80 are positioned to detect within the same plane as the  
16 light directed from the light source 120. The orientation of 180 degrees between light  
17 source 120 and light detector 80 will be preferred for smaller samples. Larger  
18 samples 30 will attenuate light transmission thus requiring the location of the light  
19 detector 80 proximal the light source 120 to insure exposure to light spectrum output  
20 82 characteristic of the sample 30. The orientation of the light source 120 and light  
21 detectors 80 is sensitive to fruit size, fruit skin and fruit pulp or flesh properties. The  
22 orientation where the sample 30 is an apple will likely preclude a 180 degree  
23 orientation because of limitations in proximity and intensity of the light source 120 as  
24 being likely to damage or burn the apple skin. However, orange skins are less  
25 sensitive and may withstand, without commercial degradation, a light source 120 of  
26 high intensity and closely positioned to the orange surface. Generally, the signal  
27 output or light detector output 82 is dependent on the orientation of the light source  
28 120 relative to the sample 30 and sample surface 35 and the light detector 80.  
29  
30



1       The light detector outputs are illustrated as providing inputs to spectrometers.  
2       The outputs may be combined to provide a single input to a single spectrum  
3       measuring and detecting instrument or may separately form inputs to separate  
4       spectrometers. For the case of a single measuring instrument, light shutters may be  
5       used and alternately activated to provide light input from each measuring location  
6       separately in series, thus producing two spectra from different depths or locations of a  
7       sample.

8       Fig. 2B and 2C depict an alternative orientation of light detectors 80 where  
9       the light detectors 80 are oriented at angle  $\theta$  of approximately 45 degrees to the  
10      direction of the light as directed by the light source 120. This illustration  
11      demonstrates two light detectors 80 positioned approximately 90 degrees apart and  
12      positioned to detect light from approximately the same plane. One of ordinary skill  
13      in the art will recognize from these illustrations that the positioning of the light  
14      source or light sources and light detector or detectors will depend on the  
15      measurement intended. Fig. 2D and 2E depict a shielding method or apparatus, e.g.,  
16      in the form of a bellows or other shield 84 article shielding the light detector from  
17      ambient light and enabling the light detector to solely detect light spectrum output  
18      from the sample. The shield 84 structure may be formed of a flexible or pliant  
19      rubber, foam or plastic which will conform to the surface irregularities of the sample  
20      and will provide a sealing function between the shielding material and sample surface  
21      which will eliminate introduction of ambient light into contact with the light detector.  
22      The shield 84 is depicted in the form of a bellows in Fig. 2D and 2E.

23      Fig. 1, 2 - 4, 6, 7 and 8 depict light sources which may be provided by  
24      spectrometers 170 (as in the case of Fig. 3) or external lamps controlled by CPU 172  
25      (as in case of Figs. 1, 2, 4 - 8). In all cases of Fig. 1 - 4, 6, 7, and 8, tungsten halogen  
26      lamps or the equivalent are used which generally produce a spectrum within the range  
27      of 250-1150 nm when the filament temperature is operated at 2500 to 3500 degrees  
28      kelvin. The light source, for the invention disclosed herein may be a broadband  
29      lamp, which for example, but without limitation, may be a tungsten halogen lamp or  
30

1 the equivalent, which may produce a spectrum within the range of 250-1150 nm;  
2 other broadband spectrum lamps may be employed depending upon the sample 30,  
3 characteristics to be predicted, and embodiment utilized The light detector 80 output  
4 82 in these embodiments will generally be received by a spectrometer 170 having a  
5 detector 200 such as a CCD array.

6 Fig. 3, 3A and 3B depict an alternative embodiment of a Nondestructive Fruit  
7 Maturity and Quality Tester-Combined Unit 15 of a combined unit 126 having a  
8 combined source/detector 135. The source of light and method of light detection in  
9 this embodiment may be a light source 120, lamp 123 and light detector 80  
10 configuration where the light source 123 lamp 123 is communicated by fiber optics  
11 from an illumination source, e.g., a lamp such as the lamp at a spectrometer 170; light  
12 detection is provided by light detectors 80, e.g., fiber optics or other manner of light  
13 transmission, positioned in varying relationships to the lamp 123 as shown in Fig. 3A  
14 and 3B. Fig. 3A is a section from Fig. 3 showing the combined unit 126 where a  
15 combined source/detector 135 has an alternative source of light and light detection;  
16 the source of light, depicted as a plurality of sources, may be sequentially fired light  
17 emitting diodes 257 emitting discrete wavelengths; the light detection may be a  
18 broadband photodiode detector 255 central to concentrically positioned LEDs. The  
19 combined unit 126 and sample holder 5 are mounted to a plate 7 or other mounting or  
20 containing fixture, case, cabinet or other device suitable for commercial or  
21 experimental purposes, for example with a bracket or other mounting article, so as to  
22 be fixed or as to have a spring or other biasing function to urge the combined unit 126  
23 and sample holder 5 against the sample. A light shield 84, as depicted in Fig. 2D and  
24 2E may be used between the combined source/detector 135 and the sample surface  
25 35. Fig. 3B is a section from Fig. 3 showing an additional embodiment of a  
26 combined unit 126 where a centrally positioned light source 120 lamp 123, for  
27 example light via fiber optics from a tungsten halogen lamp, is concentric to at least  
28 one and, as depicted here a plurality, of discrete wavelength photodetectors. The  
29 output of the at least one detection fibers or light detectors 80 is the input to a  
30

1 spectrometer 170 or other spectral measuring instrument such as a photodetector 255.  
2 Depicted is a spectrometer 170 having a detector 200. Alternatively, light source  
3 delivery and detection for the embodiment of Fig. 3B may be by a bifurcated  
4 reflectance probe; alternatively, it is recognized that a reflectance probe may provide  
5 one or more light delivery sources and one or more light detectors providing inputs to  
6 one or more spectrometer. While Fig. 3A illustrates LEDs 257 concentrically  
7 positioned around a broadband photodiode detector 255, it will be recognized that the  
8 LEDs of this embodiment, as well as the light sources 120 of other embodiments, can  
9 be placed in other arrangements, e.g., the photodiode detector 255, as well as the  
10 detectors 80 of other embodiments, can be 180 degrees opposite a circle of LEDs 257  
11 and the sample 30 placed between the LEDs 257 and the photodiode detector 255,  
12 e.g., for cherries or grapes; alternatively, the LEDs 257 can be placed on an arc,  
13 equidistant and 180 degrees opposite from the photodetector 255 in relationship to  
14 the sample 30. These two arrangements are suggestive of the positioning  
15 relationships of LEDs 257 (light sources 120), photodiode detectors 255 (light  
16 detectors 80) and samples 30 as well as the instance where other types of light source  
17 and detectors are employed including, for example, the use of filtered photodetectors  
18 255 with a broadband lamp 123, as illustrated in Fig. 5. In each embodiment the  
19 particular sample 30 type combined with the particular characteristics to be predicted  
20 will dictate the pattern of light source 120 and light detector 80 in relation to the  
21 sample 30. Additionally, it is to be recognized that light source used herein includes  
22 broadband lamps such as the tungsten halogen lamp, LEDs and other light emitting  
23 devices; light detectors used herein includes fiber optic fibers, photodiode detectors  
24 and other devices sensitive to and capable of detecting light.

25 Fig. 4 is a top plan depicting an alternative embodiment of a Nondestructive  
26 Fruit Maturity and Quality Tester 1 showing at least one light source 120 and lamp  
27 123 and light detector 50 configuration where at least one, and as depicted in this  
28 illustration two, light source 120 and lamps 123 are communicated by fiber optics to  
29 or proximal the sample surface 35, from an illumination source, e.g., a lamp 123 or  
30

1 other external light source. Light detection is provided by light detectors 80, e.g.,  
2 fiber optics or other method of light transmission. In this embodiment the light  
3 sources 120 and light detector 80 are in contact with the sample surface 35. The light  
4 detector 80 detects the light spectrum output from the sample 30 and providing light  
5 detector input 82 to a spectrum measuring or processing instrument or method  
6 including, for example, a spectrometer 170 having a detector 200. For certain  
7 samples, the light detector 80 will be inserted into the sample 30 thus effecting a  
8 shielding of the light detector 80 from ambient light, e.g., on harvester-mounted  
9 applications or in a processing plant where the product will be processed such as  
10 sugar beets or grapes. Otherwise, the light shield 84 depicted in Fig. 2D and 2E is  
11 applicable to the interrelationship of the sample 30 and sample surface 35 with the  
12 light detector 80 and light source 120 and lamp 123. Illustrated in Fig. 4 is the  
13 connection of the light detector outputs 82 from the at least one light detector 80  
14 forming the input to a spectrum measuring or processing instrument. It will be  
15 recognized that each component of this embodiment will be affixed by conventional  
16 methods to a plate 7 or other mounting or containing fixture, case, cabinet or other  
17 device suitable for commercial or experimental purposes.

18 Fig. 5 is a top plan depicting an alternative embodiment of the Nondestructive  
19 Fruit Maturity and Quality Tester 1 in a hand held case 250 showing a light source  
20 120 and at least one light detector 80, shown here as six light detectors 80,  
21 configuration in the form of a sampling head 260. In this embodiment at the  
22 sampling head 260 at least one light source 120 lamp 123 is positioned in relation to  
23 light detectors 80 provided by at least one discrete-wavelength photodetector 255.  
24 Shown in Fig. 5 are a plurality of discrete-wavelength photodetectors 255, filling the  
25 combined function of light detector 80, and spectrum detecting instrument such as a  
26 CCD array detector 200. The operation of this embodiment is seen in Fig. 1E  
27 wherein all components are encased within the case 250. Electronic and computer  
28 communication between the sampling head 260 and the computer control circuitry is  
29 via electronic signal cabling 265 or wireless including infrared or other such  
30

1 transmission method or apparatus. The sampling head 260 ambient shield 262 will  
2 provide a shielding method or apparatus, e.g., fulfilling the same or similar structural  
3 function as the shield 84 in Fig. 2D and 2E, in shielding the at least one photodetector  
4 255 and lamp 123 from ambient light. The sampling head 260 and ambient shield  
5 262, depicted in Fig. 5 and 5A may be formed from a pliable polyfoam within which  
6 the at least one lamp 123 and at least one photodetector 255 may be secured by a  
7 fixture article. The material or structure forming the sampling head 260 and ambient  
8 shield 262 may be flexible or pliable foam, in the form of a bellows or other shielding  
9 article similar to that depicted in Fig. 2D and 2E. The use of a pliable polyfoam to  
10 form the ambient shield 262 will serve to seal out or preclude exposure, by a sealing  
11 action between a sample surface 35 and the ambient shield 262, of the at least one  
12 photodetector 255 and lamp 123 from ambient light. Other shielding apparatus and  
13 methods will provide adequate shielding structure including bellows, a case or box  
14 enclosing the sampling head 260 and sample 30 or other such article providing  
15 shielding structure between ambient light and the interface between the sampling  
16 head 260, the at least one photodetector 255 and lamp 123 and the sample 30 and  
17 sample surface 35. The operation of this embodiment is seen in Fig. 1E wherein all  
18 components are encased within the case 250.

19 In this illustration, Fig. 5, the sampling head is arranged so that the  
20 photodetectors are concentrically arrayed in relation to the light source. The light  
21 source may be communicated by fiber optics from an illumination source, e.g., a lamp  
22 within the case or by placement of a lamp within the sampling head, e.g., the  
23 broadband output lamp, e.g., tungsten halogen, is physically located centrally to  
24 concentrically arrayed photodetectors. The light source may be present to be in  
25 contact with the sample surface or proximal to the sample surface. Electrical  
26 communication is effected between the light source and photodetectors and a  
27 computer processor.

28 Fig. 5 and 5A illustrate the sampling head 260 arranged so that at least one,  
29 and as illustrated in Fig. 5, a plurality of discrete-wavelength filtered 130  
30

1 photodetectors 255 are concentrically arrayed in relation to the centrally positioned at  
2 least one light source 120. The light source 120 lamp 123 which may be  
3 communicated by fiber optics from an illumination source, e.g., a lamp within the  
4 case 250 or may, for particular samples 30, e.g., oranges, be present to be in contact  
5 with or closely proximal the sample surface 35. Electrical communication and light  
6 communication is effected between the light source 120 and photodetectors 255 and a  
7 spectrometer 170 by fiber optics and or wiring, printed circuit paths, cables. The  
8 photodetectors 255 fulfill a spectrometer or spectral measurement function, provides  
9 the input 82 which will be processed with microprocessor stored calibration  
10 algorithm to produce an output representing one or more parameters of the sample.  
11 Fig. 5A is a side elevation of Fig 5 depicting a sample positioned on the sampling  
12 head.

13 Fig. 5B, 5C, 5D and 5E illustrate embodiment of the invention directed  
14 particularly to small samples 30, e.g., grapes and cherries, where the sampling head  
15 260 is in the form of a clamp 263 having at least two clamp jaws 266 which receive  
16 and secure within at least one jaw 266 structure at least one lamp 123 having a light  
17 source input 125 and in at least one clamp jaw 266 structure at least one light detector  
18 80 such that the jaws 266, when the clamp 263 is closed, receive a sample 30  
19 positioned to have the at least one lamp 123 and the at least one light detector 80  
20 proximal the sample surface 35. The light detector 80 is depicted as a fiber optic  
21 fiber transmitting spectrum from the sample to an array of filtered 130 photodetectors  
22 255 or a spectrometer 170. The output 82 will be managed as shown in Fig. 1D or  
23 1E. Fig. 5B depicts a light detector 80 as a fiber transmitting spectrum from a sample  
24 30 to be displayed on a filtered 130 photodetector array 255 where the fiber 80 is  
25 contained and positioned to transmit the detected spectrum from the sample 30 so  
26 that the fiber 80 is central to a concentrically arrayed filtered 130 photodetectors 255.  
27 A positioning structure 79, which may be tubes interconnected to position the fiber  
28 light detector 80 central to the photodetector array 255, secures and positions the light  
29 detector 80 relative to the filtered 130 photodetectors 255. A collimating lens 78 will  
30

1 be positioned between the light detector 80 fiber and the array 255 to insure that light  
2 from the light detector 80 is normal to the filtered 130 photodetector array 255. Fig.  
3 5F depicts an arc photodetector array 90 received and secured within at least one jaw  
4 266 structure where the photodetectors 255 within the photodetector array 90 are  
5 preferably equidistant from the light source 120 or lamp 123.

6 Fig. 5D is an illustration of the embodiment of Fig. 5 where the sampling  
7 head 260 is in the form of a clamp 263 having at least two clamp jaws 266 which  
8 receive and secure within at least one jaw 266 structure at least one lamp 123 and in  
9 at least one clamp jaw 266 structure at least one arc photodetector array 90 such that  
10 the jaws 266, when the clamp 263 is closed, receive a sample 30 positioned to have  
11 the at least one lamp 123 and the at least one arc photodetector array 90 proximal the  
12 sample surface 35. The arc photodetector array 90 is depicted as an array of filtered  
13 130 photodetectors 255 which will preferably be equidistant from the lamp 123 when  
14 a sample 30 is received. The output 82 will be managed as shown in Fig. 1D or 1E.

15 Fig. 6 through 6F illustrate an additional embodiment of the Nondestructive  
16 Fruit Maturity and Quality Tester 1. Fig. 6 is a top plan depicting an additional  
17 embodiment of the disclosure in a hand held case 250 form showing a light source  
18 120 in the form of LEDs 257 and light detector 80, in the form of a photodetector  
19 255, configuration in the form of a sampling head 260. With the LED 257 and  
20 photodetector 255 configuration, the photodetector 255 is used without filters, i.e.,  
21 wavelength bandpass filters, and is sensitive from ~250-1150 nm. Alternative  
22 devices or methods for providing light source and light detection includes, but is not  
23 limited to diodelasers and other light sources producing a discrete wavelength  
24 spectrum. In this embodiment at the sampling head 260 at least one LED 257, and as  
25 illustrated in Fig. 6, a plurality of LEDs 257, is positioned in relation at least one  
26 photodetector 255. A method or article is required to shield the LEDs 257 and  
27 photodetector/photodiode detector 255 from ambient light which is illustrated as an  
28 ambient shield 262 including structures of compressible and pliable foam, bellows as  
29 indicated by the shield 84 structure of Fig. 2D and 2E and other such materials,  
30

1 structures or articles. In this illustration the sampling head 260 is arranged so that the  
2 at least one photodetector/photodiode detector 255 is central to concentrically arrayed  
3 discrete wavelength LEDs 257. In this embodiment the light emitting diodes 257  
4 fulfill the function of light source and are sequentially fired or lighted with the  
5 spectrum output detected by the at least one photodetector/photodiode detector 255.  
6 The photodetector 255 output 82 is processed as demonstrated in Fig. 1F.

7       The photodetector 255 is responsive to a broad range of wavelengths, both  
8 visible and near-infrared (i.e., ~250-1150 nm). When each LED 257 is fired, the light  
9 enters the sample 30, interacts with the sample 30, and re-emerges to be detected by  
10 the photodetector 255. The photodetector 255 produces a current proportional to the  
11 intensity of light detected. The current is converted to a voltage, which is then  
12 digitized using an analog-to-digital converter. The digital signal is then stored by an  
13 embedded microcontroller/microprocessor. The microcontroller/microprocessor used  
14 in the preferred embodiment is an Intel 8051. However, other microprocessors and  
15 other devices and circuits will perform the needed tasks. The signal detected by the  
16 photodetector 255 as each LED 257 is fired is digitized, A/D converted and stored.  
17 After each LED 257 has been fired and the converted signal stored, the  
18 microprocessor stored readings are combined to create a spectrum consisting of as  
19 many data points as there are LEDs 257. This spectrum is then used by the embedded  
20 microprocessor in combination with a previously stored calibration algorithm to  
21 predict the sample properties of interest. Signal processing then proceeds as shown  
22 in Fig. 1F. Fig. 6A is a section elevation of Fig 6 depicting the sampling head 260  
23 showing the ambient shield 262, composed for example of compressible foam or  
24 bellows or other such structure, e.g., a rubber plunger, originally designed for a  
25 vacuum pick-up tool which looks much like a toilet plunger, but has a more gentle  
26 curve and is available in a variety of sizes including 1mm diameter and larger; in  
27 certain of these embodiments a 20 mm rubber plunger was used with a pickup fiber  
28 optic operating as the "handle" that couples to the plunger. The sample then makes a  
29 seal with the plunger prior to measurement. Other devices or methods will also  
30



1 provide the requisite sealing structure, as described in this specification. Also shown  
2 are light emitting diodes 257 and light detector/photodiode detector 80 fixed by  
3 affixing articles within the sampling head 260. The affixing articles will be  
4 composed of bracket articles and other mounting structure recognized by one of  
5 ordinary skill. The output 82 from the light detector 80 is depicted as well as the case  
6 250 with processing as shown in Fig. 1F..

7 Fig. 6B, 6C and 6D are representative of an additional embodiment of the  
8 disclosure of this invention where a sampling head 260 is affixed in a case 250, light  
9 detectors 80 are affixed by affixing articles within the sampling head 260. The  
10 sampling head 260 receives a sample 30 which is positioned to be illuminated by a  
11 light source 120 lamp 123. This embodiment depicts the case 250 as having a cover  
12 which serves as an ambient shield 262. Additionally, the structure of the sampling  
13 head 260 may be of a compressible or pliable foam or a bellows which may provide  
14 the structure allowing an ambient shield 262. Ambient light can also be measured  
15 after the sample 30 is in place, but before the light source 120 lamp 123 is turned on.  
16 This ambient light signal is then stored and subtracted accordingly for subsequent  
17 measurements. A light source input power 125 is depicted for example from a  
18 spectrometer 170 or may be from a CPU 172 trigger or other external lamp source  
19 and/or power supply. Outputs 82 from the light detector/photodiode detectors 80 are  
20 depicted and processed as shown in Fig. 1F.

21 Fig. 6C is a plan view of the embodiment of Fig. 6B illustrating a plurality of  
22 light detectors, illustrated here as fiber optic light detectors. Shown in this  
23 illustration are two light detectors with one proximal the light source and another  
24 distal from the light source with the purpose being to provide two different  
25 pathlengths, shallow and deep, by taking the difference between the far or deep  
26 spectrum and the near or shallow spectrum data of greater accuracy can be obtained.  
27 This difference method provides a pathlength correction to improve concentration or  
28 property or sample characteristic predictions.

29

30

1           Fig. 6E and 6F are representative of an embodiment of the disclosure wherein  
2 the lamp 123 is positioned within the sampling head 260. Alternatively, the lamp 123  
3 may be positioned by an affixing article within the ambient shield 262.

4           Another embodiment in a packing/sorting line form of the disclosure is  
5 depicted in Fig. 7, 7A and 7B illustrating a light source 120 and light detector 80  
6 affixed and positioned by bracket articles 275, light detector fixture 50 and light  
7 source securing articles 122 which will be recognized as mounting structure from  
8 which at least one light source 120 and at least one light detector 80 will be  
9 suspended, rigidly secured and otherwise positioned including the use of such as rods,  
10 bars and other such bracket article 275 fixtures . The at least one light source 120 is  
11 positioned to illuminate a sample 30, depicted in this drawing as an apple. The at  
12 least one light detector 80 is positioned by bracket articles 275 and light detector  
13 fixture 50 to detect the light spectrum output from the illuminated sample 30.  
14 Samples 30, in this illustration are conveyed by a sample conveyor 295. Total  
15 exposure to the at least one light source 120 and at least one light detector 80 will be  
16 determined by the intensity of the light source used and the nature of the sample  
17 being interrogated. For apples, exposure times of 5-10 msec or less are commonly  
18 used to provide multiple measurements per apple at line speeds up to 20 fruit/second.  
19 The at least one light detector 80 depicted in Fig. 7 illustrates a separation of the light  
20 detector 80 from the light source 120 of approximately 90 degrees with both light  
21 detector 80 and light source 120 essentially orthogonal to the sample in the same  
22 plane. However, for each embodiment of this disclosure, the positioning of the light  
23 detector(s) 80 and of the light sources(es) 120 relative to each other and relative to  
24 the sample is dependent on the characteristics of the sample and of the qualities  
25 sought to be measured. For example, the light source 120 may be positioned to be  
26 directed essentially orthogonal to the sample surface 30 in a plane oriented 90 degrees  
27 from the plane to which the light detector 80 is directed. The light source 120 and  
28 light detector 80 are positioned proximal the sample 30. The light source 120 lamp  
29 123 may be powered from a spectrometer 170 or other external source, as noted in the  
30

1 discussion of Fig. 1. The light detector 80 may be a single fiber optic fiber with the  
2 light spectrum detected forming the output 82 to a spectrum detection instrument  
3 such as a spectrometer 170 and detector 200. The processing of the light spectrum  
4 detected is as described and set out in Fig. 1C.

5 Another embodiment directed to sorting/packing lines is seen in Fig. 7C, 7D.  
6 and 7E depicting at least one light detector 80 and as shown a plurality of light  
7 detectors 80 representative of measurements of a plurality of spectrum regions. A  
8 filtered 130 light detector 80 is representative of the detection of spectrum of 700 to  
9 925nm, another light detector 80 is representative of detection of red pigments and  
10 chlorophyll in the 500 to 699 nm range and water, alcohols and physical quality (e.g.,  
11 firmness, density) information available in the 926 to 1150 nm range, another light  
12 detector 80 is representative of detection of the yellow pigment region in the range of  
13 250 to 499 nm. Two additional light detectors 80 are shown positioned opposite a  
14 light source 120 lamp 123 such that the sample will pass between the lamp 123 and  
15 light detector 80 and is representative of an input to two reference spectrometers 170,  
16 one monitoring the 250-499 nm wavelength region and the other monitoring the 500-  
17 1150 nm region.. Where the sample is an apple it will be expected that the reference  
18 channel additionally will not detect spectrum out of the sample and will indicated the  
19 presence or absence of a sample. The output of the reference channel(s) can be used  
20 as an object locator to determine which spectra from the sample light detector(s) to  
21 retain for use in prediction. Shielding may be utilized between the light source 120  
22 lamp 123 and the light detectors 80 and or sample 30, e.g., options include but are not  
23 limited to 1) a light shield 284 as a curtain 285 may extend from a bracket fixture 275  
24 between the light source 120 lamp 123 and light detectors 80 reducing the direct  
25 exposure of the light detectors 80 to the light source 120 lamp 123, 2) the light shield  
26 285 may extend between the light source 120 lamp 123 and light detectors 80 and  
27 sample 30 wherein an aperture will be formed in the light shield 284 between the  
28 light source 120 lamp 123 and sample 30 limiting surface reflection from the sample  
29 surface 35 to the light detectors 80 and 3) the light shield 284 may provide filter 130  
30

1 function, e.g., heat blocking, cutoff and bandpass, between the light source 120 lamp  
2 123 and sample surface 35 limiting the possibility of heat or burn damage to the  
3 sample 30.

4 An additional embodiment is seen in Fig. 8, 8A and 8B wherein at least one  
5 light shield 284 is positioned by a bracket article 275 to separate the at least one light  
6 source 120 and lamp 123 from the at least one light detector 80 as a sample 30 is  
7 conveyed by a sample conveyor 295 under and past a light source 120 and lamp 123  
8 toward and under a light detector 80. The light shield 284 may be a curtain 285 and  
9 is depicted in Fig. 8 as a curtain 285 composed of at least one portions and as shown  
10 in Fig. 8A of two portions or a plurality of portions, each suspended from a bracket  
11 article 275. Where there are a plurality of curtain 285 portions, the respective curtain  
12 285 portions will overlap and separate as the sample 30 passes.

13 In this embodiment, as shown in Fig. 8, the sample 30, for example an apple,  
14 is conveyed by a packing/sorting conveyance system 295. A cycle will be repeated as  
15 each sample 30 moves toward, into contact with, under and past the light shield 284.  
16 The packing/sorting conveyance system 295 will have samples 30 sequentially  
17 positioned on the conveyance system 295 such that the space between sample 30 is  
18 minimal generally in relation to the size of the sample 30. As the sample 30 moves  
19 toward, but is not in contact with, the light shield 284 the sample 30 will be  
20 illuminated by the light source 120 while the light detector 80 will detect only  
21 ambient light and will be shielded from the light source 120. As the sample 30  
22 moves into contact with and under the light shield 284 the sample 30 will, while  
23 continuing to be illuminated by the light source 120, be exposed to the light detector  
24 80 which will detect spectrum from the sample 30. When the sample 30 moves past  
25 the light shield 284 the light detector 80 will again be shielded from the light source  
26 120 and will detect only ambient light. The light source 120 may, for example, be a  
27 tungsten/halogen lamp or light transmitted by optics to illuminate the sample 30. The  
28 light detector 80, for example a optic fiber detector, is positioned such that the sample  
29 surface 35 will be proximal to the light detector 80 as the sample 30 contacts and  
30

1 passes under the light shield 284. The light shield 284 may be composed of a flexible  
2 or pliable sheet opaque to the spectra to which the light detector 80 is sensitive and  
3 may be comprised, for example, of silicone rubber, Mylar, thermoplastics and other  
4 materials. The light detector 80, light shield 284 and light source 120 will be  
5 mechanically affixed by bracket articles 275 or other mounting apparatus or methods  
6 readily recognized by those of ordinary skill in the art or measurement at  
7 packing/sorting systems.

8       An alternative configuration of the embodiments of Fig. 7 and 8 will employ a  
9 plurality of light sources 120 including, for example a light source 120 illuminating  
10 the sample 30 from the top with a second light source 120 illuminating the sample 30  
11 from the side or two light sources 120 illuminating the sample 30 from opposite sides  
12 illustrating the multiple positions which may be employed for light sources 120. A  
13 plurality of light detectors 80 will view the same or different sample surface 35  
14 locations with each light detector 80 output 82 either sensed by a separate  
15 spectrometer or combined to form a single output 82. Where a plurality of outputs 82  
16 are received by a plurality of spectrometers 170 at least one spectrometer 170 will  
17 have a neutral density filter installed to block some percentage, e.g. 50%, of the  
18 output 82 from the light detector 80 with this spectrometer 170 to provide data from a  
19 particular spectral range, e.g., approximately 700 to approximately 925 nm. A second  
20 spectrometer will not use a filter and will saturate from approximately 700 to 925 nm  
21 but will yield good signal to noise (S/N) data from approximately 500 to 699 nm and  
22 approximately 926 to 1150 nm. Other outputs 82 to filtered input spectrometers 170  
23 will permit the examination of specific spectral ranges. Additionally, this method  
24 allows the use of the same exposure times on both, or a plurality of, spectrometers  
25 170 making them easier to control in parallel. This is essentially the dual exposure  
26 approach using filtered input 82 to the spectrometer 170 rather than different  
27 exposure times. The blocking of light to one spectrometer 170 effects the same result  
28 as using a shorter exposure time. The dual intensity approach proves problematic  
29 because the high and low intensity spectra are not easily pasted or combined together  
30

1 due to slope differences in the spectra, however the dual intensity approach may be  
2 preferred for predicting certain parameters (e.g., firmness, density ) with certain  
3 sample types (e.g. stored fruit or oranges). While the dual exposure approach yields  
4 excellent combined spectra, both approaches provide useable combined spectra,  
5 which are necessary for firmness and other parameter prediction and also improved  
6 Brix accuracy.

7 Typically, Partial Least Squares (PLS) regression analysis is used during  
8 calibration to generate a regression vector that relates the VIS and NIR spectra to  
9 brix, firmness, acidity, density, pH, color and external and internal defects and  
10 disorders. This stored regression vector is referred to as a prediction or calibration  
11 algorithm. Spectral pre-processing routines are performed on the data prior to  
12 regression analysis to improve signal-to-noise (S/N), remove spectral effects that are  
13 unrelated to the parameter of interest, e.g., baseline offsets and slope changes, and  
14 "normalize" the data by attempting to mathematically correct for pathlength and  
15 scattering errors. A pre-processing routine typically includes "binning", e.g.,  
16 averaging 5-10 detector channels to improve S/N, boxcar or gaussian smoothing (to  
17 improve S/N) and computation of a derivative. The 2nd derivative is most often  
18 used, however, the 1st derivative can also be used and the use of the 4th derivative is  
19 also a possibility. For firmness prediction, data is often used after binning,  
20 smoothing and a baseline correction or normalization; where no derivative is used.  
21 For Brix and other chemical properties, a 2nd-derivative transformation often is best.

22 Using a Principal Components Analysis (PCA) classification algorithm, soft  
23 fruit and very firm fruit can be uniquely identified from moderately firm fruit. Also,  
24 under-ripe and ripe fruit can be separated and spoiled, e.g., higher pH, or rotten fruit  
25 can be identified for segregation. The NIR spectra of whole apples, and other fruit, in  
26 the approximately 250-1150 nm region also show correlation with pH and total  
27 acidity. The 250-699 nm wavelength region contains color information, e.g.,  
28 xanthophylls, yellow pigments, absorb in the 250-499 nm region; anthocyanin, which  
29 is a red pigment, has an absorption band spanning the 500-550 nm region, improves  
30

1 classification or predictive performance, particularly for firmness. An example is the  
2 prediction of how red a cherry is by measuring and applying or comparing the  
3 anthocyanin absorption at or near 520 nm to the pertinent predictive or classification  
4 algorithm. Under-ripe oranges, having a green color, can be predicted by  
5 measurement of sample spectrum output 82 in the chlorophyll absorption region  
6 (green pigments) at or near 680 nm and applying the measured output 82 spectrum to  
7 the pertinent predictive algorithm. The spectrum output from the sample, in the 950-  
8 1150 nm region has additional information about water, alcohols and acids, and  
9 protein content. For example, sample water content relates to firmness in most fruit  
10 with water loss occurring during storage. High pH fruit, often indicative of spoilage,  
11 can also be uniquely identified in the presence of other apples using a classification  
12 algorithm.

13       The present disclosure is a non-destructive method and apparatus for  
14 measuring the spectrum of scattered and absorbed light, particularly within the NIR  
15 range of 250-1150 nm, for the purpose of predicting, by use of the applicable  
16 predictive algorithm, particular fruit characteristics including sugar content, firmness,  
17 density, pH, total acidity, color and internal and external defects. These fruit  
18 characteristics are key parameters for determining maturity, e.g., when to pick, when  
19 to ship, when and how to store, and quality, e.g., sweetness/sourness ratio and  
20 firmness or crispness for many fruits and vegetables. These characteristics are also  
21 indicators of consumer taste preferences, expected shelf life, economic value and  
22 other characteristics. Internal disorders can also be detected, e.g., for Tasmania  
23 Jonagold apples, including disorders such as water core, core rot, internal  
24 browning/breakdown, carbon dioxide damage, and, in some cases, insect  
25 damage/infestation. The disclosure simultaneously utilizes 1) the visible absorption  
26 region (about 250-699 nm) that contains information about pigments and chlorophyll,  
27 2) the wavelength portion of the short-wavelength NIR that has the greatest  
28 penetration depth in biological tissue, especially the tissue of fruits and vegetables  
29 (700-925 nm), and 3) the region from 926-1150 nm, which contains information  
30

1 about moisture content and other O-H components such as alcohols and organic acids  
2 such as malic, citric, and tartaric acid.

3       Benchtop, handheld, portable and automated packing/sorting embodiments  
4 are disclosed. The benchtop embodiment will generally be distinguished from the  
5 high speed packing/sorting embodiment through the greater ease of examining the  
6 sample 30 with more than one intensity light source 120, i.e., lamps 123 or light  
7 sources 120 controlled with more than one voltage or power level or more than one  
8 exposure time. A benchtop embodiment discussed herein utilizes a dual intensity  
9 light source 120, e.g., by utilizing dual voltages or dual exposure times or other  
10 methods of varying the intensity of the light source 120 used to illuminate the sample  
11 30. Alternatively, the light detector 80 may be operated to provide at least one  
12 exposure at one lamp 123 intensity and, for example, the light detector 80 may  
13 provide dual or a plurality of exposures at 1 lamp intensity. The method of providing  
14 dual or a plurality of exposures at one lamp intensity is accomplished as follows: the  
15 light detector 80 exposure time is adjustable through basic computer software control.  
16 In the computer program, two spectrum of different exposure times are collected for  
17 each sample 30. The benchtop method may, as preferred by the operator, involve  
18 direct physical contact between the sample surface 35 and the apparatus delivering  
19 the light source 120, e.g., at least one light detector 80 may penetrate the sample  
20 surface 35 into the sample interior. A high speed packing/sorting embodiment  
21 generally will be limited in the delivery or the exposure of the light source 120,  
22 relative to or at the sample surface 35, resulting from the limited time, usually a few  
23 milliseconds, the sample 30 will be in range of the light source 120. Multiple passes  
24 or arrangements of multiple light sources 120 and multiple light detectors 80,  
25 including photodetectors 255 and other light detection devices, will permit, in the  
26 highspeed packing/sorting embodiment, the exposure of the sample to multiple light  
27 source 120 intensities. The handheld embodiment generally will allow sampling of a  
28 limited number of items by orchard operators, i.e., in inspection of fruit samples on  
29  
30



1 the plant or tree, and from produce delivered for packing/sorting, to centralized  
2 grocery distribution centers or individual grocery stores.

3       Obtaining data over the wavelength region of 250-1150 nm is only possible  
4 using a multi intensity or multi exposure measurement, i.e., dual intensity or dual  
5 exposure as in the preferred embodiment. While one spectrometer can be used to  
6 cover the 500-1150 nm region, a second spectrometer is necessary to cover the 250-  
7 499 nm region. The number of different light source intensity or exposures required  
8 is dependent on the characteristics of the sample and of the detector 200. The  
9 spectrum acquired at longer detector 200 exposure times or higher light source  
10 intensity saturates the detector pixels, for some detectors, e.g., Sony ILX 511, or  
11 Toshiba 1201, from ~700-925 nm, yet yields excellent S/N data from ~500-699 nm  
12 and from ~926-1150 nm. The low intensity or shorter exposure time spectrum is  
13 optimized to provide good S/N data from 700-925 nm. Accurate firmness predictions  
14 of fresh and stored fruit requires the 700-925 nm region and the 500-699 nm, e.g.,  
15 pigment and chlorophyll, plus the 926-1150 nm region. Addition of the 250-499 nm  
16 region, e.g., yellow pigments known as xanthophylls which absorb light, will  
17 improve prediction of firmness and other parameters such as Brix, acidity, pH, color  
18 and internal and external defects. There is high correlation between the spectrum  
19 output from the sample 30 in the 926-1150 nm region with water content. Stored  
20 fruit appears to have higher relative water content than fresh fruit and less light  
21 scattering. The chlorophyll and pigment of a sample 30 is predicted by correlation  
22 with the sample spectrum output 82 in the 250-699 nm region, with this correlation  
23 likely being the most important for prediction of firmness of fresh fruit, while the  
24 longer wavelength water region may be more important for accurate firmness  
25 measurement of stored fruit.

26       Just as in the longer NIR wavelength regions, the 700-925 nm region also  
27 contains absorption bands from carbon-hydrogen, oxygen-hydrogen, and nitrogen-  
28 hydrogen bonds, e.g., (CH, OH, NH). In the case where protein is key component of  
29 interest, the 926-1150 nm region is of greatest interest. However, pre-sprout  
30

1 condition in grain, for example, can be predicted by examination of the sample  
2 output spectrum in the 500-699 nm region.

3       The preferred embodiment of the apparatus is composed of at least one light  
4 source 120, a sample holder 5 including, for example a sorting/packing sample  
5 conveyor 295 and other devices and methods of positioning a sample 30, with at least  
6 one light detector 80, i.e. optical fiber light sensors in the preferred embodiment,  
7 detecting the sample spectrum output 82 to be received by a spectrum measuring  
8 instrument such as a spectrometer 170 with a detector 200, e.g., a CCD array, with  
9 the signal thus detected to be computer processed, by a CPU 172 having memory,  
10 and compared with a stored calibration algorithm, i.e., stored in CPU 172 memory,  
11 producing a prediction of one or more characteristics of the sample. The at least one  
12 light source 120 and at least one light detector 80 are positioned relative to the sample  
13 surface 35 to permit detection of scattered and absorbed spectrum issuing from the  
14 sample. Bracket fixtures 275, brackets and other recognized positioning and affixing  
15 devices and methods will be employed to position light sources 120, light detectors  
16 80 and sample holders 5. In the preferred embodiment the positioning of the light  
17 source 120 and light sensor or light detector 80 will be such as to shield 84 the light  
18 detector 80 from direct exposure to the light source 120 and will limit the light  
19 detector 80 to detection or exposure of light transmitted from the light source 120  
20 through the sample 30. The light source 120 may be fixed in a conical or other cup or  
21 shielding container which will allow direct exposure of the light source 120 to the  
22 sample surface while shielding the light source 120 from the light detector 80.  
23 Alternatively, the light detector 80 may be fixed in a shielding container, e.g., a shield  
24 84 or ambient shield 262, thus shielding the light detector 80 from the light source 80  
25 and exposing the light detector 80 solely to the light spectrum transmitted through the  
26 sample 30 from the light source 80 to the light detector 80. The spectrum detected by  
27 the light detectors 80, i.e., the signal output 82, is directed, as input, to at least one  
28 spectrometer 170 or other device sensitive to and having the capability of receiving  
29 and measuring light spectrum. In the preferred embodiment two or more  
30

1 spectrometers 170 are employed. One spectrometer 170 monitors the sample  
2 channel, i.e., the light detector 80 output 82, and another spectrometer 170 monitors  
3 the reference, i.e., light source 120 channel. If the lamp 123 is turned on and off  
4 between measurements, ambient light correction can be done for both light detector  
5 80 and light source 120 channel, e.g., spectrum collected with no light is subtracted  
6 from spectrum collected when lights are on and stabilized. Alternatively, the light  
7 source 120 can be left on and ambient light can be physically eliminated using a  
8 shield 84 or ambient shield 262, such as a lid or cover or appropriate light-tight box.  
9 The discussion of shielding of the light detector 80 composed of fiber optic fibers  
10 applies as well to photodetectors 255 and the utilization of light sources other than  
11 tungsten halogen lamps including for example light emitting diodes 257.

12 Another alternative with multiple sampling points and thus multiple light  
13 detectors 80, as with fiber-optic sensors, is to converge all or some sampling points,  
14 as depicted in Fig. 4, back to a single sample or light detector 80 channel  
15 spectrometer 170, e.g., using a bifurcated, trifurcated or other multiple fiber-optic  
16 spectrometer 170 input. Multiple or a plurality of sample points, i.e., light detectors  
17 80, provides better coverage of a sample 30, e.g., sampling is more representative of  
18 the sample 30 as a whole, or allows multiple points, e.g., on a conveyor belt full of  
19 product, to be measured by a single spectrometer 170 thus providing an "average"  
20 spectrum that is used to predict an average property such as Brix for all sample 30 or  
21 light detector 80 channels.

22 In the preferred embodiment two or more spectrometers 170, or at least two  
23 spectrometers 170 are used for reference and or measurement. A spectrometer 170  
24 used in gathering data for this invention utilized gratings blazed at 750 nm to provide  
25 coverage from 500-1150 nm. Additionally, spectrometers 170 operating in the 250-  
26 499 nm wavelength region can be included to provide expanded coverage of the  
27 visible region where xanthophylls, e.g., yellow pigments, absorb light. Information in  
28 the output 82 spectrum detected from 1000-1100 nm also contains repeated  
29 information, if a cutoff or long-pass filter is not used, from 500-550 nm, e.g.,  
30